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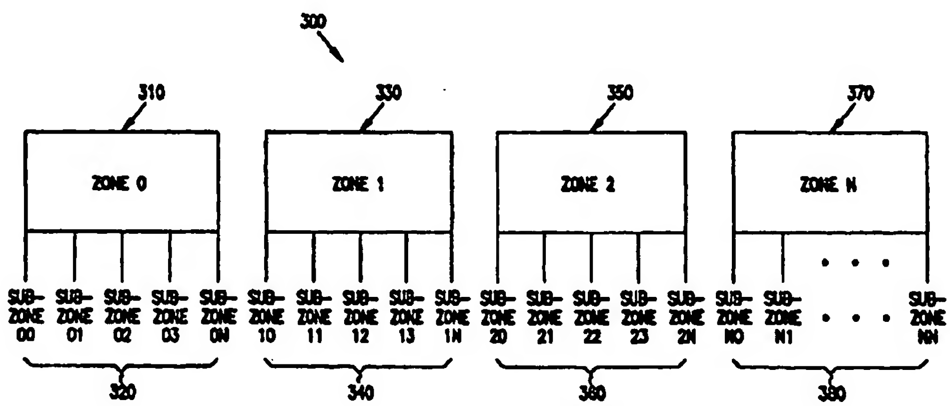

(57) Abstract

A method to dynamically map known lower performing heads for disc drives in order to reduce the likelihood of expensive manufacturing rework being conducted on the entire drive. Using the head in a drive that is performing well or better than average, the method allows one to record more bits per density on that specific head. This is especially true where zone recording (300) is done, otherwise known as defining the recording density for a group of cylinders (310, 330, 350, 370). Frequency-adjusting of heads (lowering the recording frequency) within a cylinder allows for variable logical block addressing schemes that correspond to a user's preferred data accessing layout. Several tracks may be accessed, while others can be reserved for system data. The method described works particularly well in a headerless architecture environment. The performance of lower performing or "poor" heads can be improved.

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VARIABLE DISC DRIVE CYLINDER RECORDING SYSTEM

Field of the Invention

The present invention relates to the field of mass storage devices. More particularly, this invention relates to a system for varying the recording frequency on a head basis within a cylinder of a disc drive.

Background of the Invention

One of the key components of any computer system is a place to store data. Computer systems have many different places where data can be stored. One common place for storing massive amounts of data in a computer system is on a disc drive. The most basic parts of a disc drive are a disc that is rotated, an actuator that moves a transducer to various locations over the disc, and electrical circuitry that is used to write and read data to and from the disc. The disc drive also includes circuitry for encoding data so that it can be successfully retrieved and written to the disc surface. A microprocessor controls most of the operations of the disc drive as well as passing the data back to the requesting computer and taking data from a requesting computer for storing to the disc.

The transducer is typically housed within the slider. The slider is a small ceramic block which is passed over the disc in a transducing relationship with the disc. The small ceramic block, also referred to as a slider, is usually aerodynamically designed so that it flies over the disc. Most sliders have an air bearing surface ("ABS") which includes rails and a cavity between the rails. When the disc rotates, air is dragged between the rails and the disc surface causing pressure, which forces the head away from the disc. At the same time, the air rushing past the depression in the air bearing surface produces a negative pressure area. The negative pressure or suction counteracts the pressure produced at the rails. The slider is also attached to a load spring which produces a force on the slider directed toward the disc surface. The various forces equilibrate so the slider flies over the surface of the disc at a particular fly height. The fly height is the thickness of the air lubrication film or the distance between the disc surface and the transducing head. This film eliminates the friction and resulting wear that would occur if the transducing head and disc were in mechanical contact during disc rotation. In some disc drives, the slider passes through a layer of lubricant rather than flying over the surface of the disc.

Information representative of data is stored on the surface of the memory disc. Disc

drive systems read and write information stored on tracks on memory discs. Transducers, in the form of read/write heads attached to the sliders, located on both sides of the memory disc, read and write information on the memory discs when the transducers are accurately positioned over one of the designated tracks on the surface of the memory disc. The transducer is also said to be moved to a target track. As the memory disc spins and the read/write head is accurately positioned above a target track, the read/write head can store data onto a track by writing information representative of data onto the memory disc. Similarly, reading data on a memory disc is accomplished by positioning the read/write head above a target track and reading the stored material on the memory disc. To write on or read from different tracks, the read/write head is moved radially across the tracks to a selected target track. The data is divided or grouped together on the tracks. In some disc drives, the tracks are a multiplicity of concentric circular tracks. In other disc drives, a continuous spiral is one track on one side of a disc drive. Servo feedback information is used to accurately locate the transducer. The actuator assembly is moved to the required position and held very accurately during a read or write operation using the servo information.

Where the head actuator holds all the heads corresponding to all the discs together in the same proximate radial location, a vertical stack of tracks is formed, thus resembling a cylinder. In other words, a "cylinder" is the combination of all the tracks at a given radial position or at a given head actuator position. Moreover, as used herein, the term "zone" refers to a group of one or more cylinders. A zone appears on a single disc surface as a group or band of recording tracks. In the past, disc drives have had a single "recording frequency", defined as the frequency of writing to or inputting of data on a disk rotating at a fixed angular velocity, for all heads within a zone. In a disc drive typically each surface of the disc has an associated read/write head or transducer. The transducers are on an E-block or comb which is a series of arms located so that a gang of transducers can be moved in unison. During write and read operations, each head is separately turned on and off from the others. The disc surface has zones with different values of the recording density that is typically measured in bits per inch. As the disc spins at a substantially constant rate, different recording frequencies are associated with each zone. At the outer radial zones, the recording frequency is higher. The data density is also higher at the outer radial zones. In general, the disc drive industry characterizes this reorganization as "zone-bit recording", because of the relational integration of zones with changing recording density values.

Recent attempts to improve read/write head (also referred to herein as "head" or

"heads") yields have resulted in a hardware zone structure and software that allows the recording frequency to vary uniformly within the zone. In other words, the recording frequency of all the heads within a zone are varied to cover for any poor performing heads. By lowering the recording frequency of all the heads within a zone, the performance of the "poor" heads can be improved. The result is a loss in recording frequency of all the heads within a zone. The data capacity also declines when the write frequency is lowered. The degree to which the recording frequency is lowered depends on the number of heads in the drive and also the amount of margin the good heads have. Some attempts to improve head yields require a constant recording frequency for all heads within a cylinder.

What is needed is a disc drive that is capable of achieving better error rates to overcome poor yield problems and that increases overall performance of the "poor" heads.

Summary of the Invention

The invention is a method to dynamically map known defective heads for disc drives in order to reduce the likelihood of expensive manufacturing rework being conducted on the entire drive. Using the head in a drive that is performing well or better than average, the method allows one to record more bits per inch or record of a higher frequency on that specific head. This is especially true where zone recording is done, otherwise known as defining the recording density for a group of cylinders.

In one embodiment, a method for improving reading and writing information to a disc of a disc drive includes reading and writing information at a first frequency when in a first zone with a first head and reading and writing information at a second frequency when accessing a second storage surface within the same first zone. Part of the method includes determining that at least one read/write transducer will produce less errors if working at a different frequency than an initially assigned frequency.

The method is used on a disc drive. The disc drive includes a rotating disc assembly having a first disc surface and a second disc surface. A first read/write transducer operates in a transducing relationship to the first disc surface and at a first frequency in a first disc zone. A second read/write transducer operates in a transducing relationship to the second disc surface but at a different frequency than the first frequency when operating in the first disc zone.

In another embodiment, a magnetic disc storage system, includes a magnetic disc having two recording surfaces. A read/write transducer is positioned near each of the

recording surfaces of the magnetic disc for reading and writing information on each of the recording surfaces. A memory is coupled within the disc storage system and coupled to the read/write transducer. The memory contains an offset value of a servo position. A controller is also coupled within the disc storage system and coupled to the read/write transducer and the memory. The controller positions the read/write transducer in the disc storage system over a target address as a result of an input based on number of frequency-adjusted heads.

In yet another embodiment, a system for reusing a lower performing read/write head, includes number of recording zones for storing data. A variance in frequency among recording zones decreases the overall the error rate caused by the read/write heads. A zone table is used to determine a target zone and the number of heads serviced by a zone.

Advantageously, the method described works particularly well in a headerless architecture environment. The performance of the lower performing heads can be improved. Moreover, better error rates are achieved, thus overcoming yield problems. The invention may result in an increased accuracy of the "arithmetic logic unit (ALU) resource", i.e., a "computing resource", without having to change the engine that performs the calculations. In one aspect of the present invention, a "computing resource" includes the programmable logic, a computer, an ALU, a controller, or similar functional apparatus capable of calculating zones and head specifications for using lowered recording frequency as derived from error rates. In addition, it is less likely that the drives will have to be discarded or reworked, as a result of lower performing heads.

Brief Description of the Drawings

FIG. 1 is an exploded view of a disc drive with a multiple disc stack and a ramp assembly for loading and unloading transducers to and from the surfaces of the discs.

FIG. 2 is a block diagram of a recording channel.

FIG. 3 shows the surface of a disc divided into zones.

FIG. 4 is a pictorial depiction of the grid-like layout of a disc drive.

FIG. 5 is a block diagram of original zones reorganized into subzones.

FIG. 6 is a graphical depiction of bit density formatting in subzones.

FIG. 7 is a pictorial depiction of sequential read/write access.

FIG. 8 is a pictorial depiction of serpentine read/write access.

FIG. 9 is a flowchart of a method for improving the error rate of a disc drive.

FIG. 10 is a schematic view of a computer system.

Description of the Preferred Embodiment

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The invention described in this application is useful with all mechanical configurations of disc drives having either rotary or linear actuation. In addition, the invention is also useful in all types of disc drives including hard disc drives, zip drives, floppy disc drives and any other type of drives where unloading the transducer from a surface and parking the transducer may be desirable. FIG. 1 is an exploded view of one type of a disc drive 100 having a rotary actuator. The disc drive 100 includes a housing or base 112, and a cover 114. The base 112 and cover 114 form a disc enclosure. Rotatably attached to the base 112 on an actuator shaft 118 is an actuator assembly 120. The actuator assembly 120 includes a comb-like structure 122 having a plurality of arms 123. Attached to the separate arms 123 on the comb 122, are load beams or load springs 124. Load beams or load springs are also referred to as suspensions. Attached at the end of each load spring 124 is a slider 126 which carries a magnetic transducer 150. The slider 126 with the transducer 150 form what is many times called the head. It should be noted that many sliders have one transducer 150 and that is what is shown in the figures. It should also be noted that this invention is equally applicable to sliders having more than one transducer, such as what is referred to as an MR or magneto resistive head in which one transducer 150 is generally used for reading and another is generally used for writing. On the end of the actuator arm assembly 120 opposite the load springs 124 and the sliders 126 is a voice coil 128.

Attached within the base 112 is a first magnet 130 and a second magnet 130'. As shown in FIG. 1, the second magnet 130' is associated with the cover 112. The first and second magnets 130, 130', and the voice coil 128 are the key components of a voice coil motor which applies a force to the actuator assembly 120 to rotate it about the actuator shaft 118. Also mounted to the base 112 is a spindle motor. The spindle motor includes a rotating portion called the spindle hub 133. In this particular disc drive, the spindle motor is within the hub. In FIG. 1, a number of discs 134 are attached to the spindle hub 133. In other disc drives a single disc or a different number of discs may be attached to the hub. The invention described herein is equally applicable to disc drives which have a plurality of discs as well as

disc drives that have a single disc. The invention described herein is also equally applicable to disc drives with spindle motors which are within the hub 133 or under the hub.

Referring now to FIG.2, there is shown a block diagram of a partial-response maximum-likelihood (PRML) recording channel available in the disk drive 100. Information to be written is applied to an encoder 1001 for providing a modulation coded output having predefined run length constraints, such as for the minimum and maximum number of consecutive zeros and the maximum run length of zeros in the even and odd recorded sequences in the overall recorded sequence. A precoder 1002 follows the encoder 1000 described by a $1/(1-D^2)$ operation where D is a unit delay operator. A PRML precomp 1004 (partial-response maximum-likelyhood precompensation circuit) coupled to the precoder 1002 provides a modulated binary pulse signal applied to a write circuit 1006 that provides the modulated write current for writing to the disk surface. An analog read signal is obtained at head and disk block 1008 described by the $(1 - D^2)$ operation. The read signal is applied to a variable gain amplifier (VGA) 1009 and the amplified read signal is applied to a lowpass filter 1010 which may or may not provide equalization for class IV response. The filtered read signal is converted to digital form by an analog to digital converter (ADC) 1012 that provides 64 possible 6-bit sampled values. Gain and timing control circuitry are generally designated by the reference character 1014. Typically, the 6-bit samples of the ADC 1012 are applied to a digital filter 1016, such as a 10 tap finite impulse response (FIR) digital filter. The filtered signal from the digital filter 1016 is applied to a Viterbi decoder 1018 coupled to a decoder 1020 to complete the maximum-likelihood (ML) detection process for data read back.

Gain and timing control functions involve an acquisition mode of operation and a tracking mode of operation. During the acquisition mode, the gain and timing control circuitry 1022, 1026 locks onto a predetermined data pattern called the sync field setting the VGA amplitude to a determined voltage level and setting the ADC sampling phase to achieve proper lock-on to the sync field. After the loops have converged during the tracking mode, the gain and timing control circuitry 1022, 1026 tracks customer data making sure the signal remains locked.

Gain and timing control circuitry includes an acquisition gain and timing control 1022 having digital signals supplied by the ADC 1012 at lines 1013. During the acquisition mode of operation, acquisition gain and timing control 1022 generates a digital gain control signal on lines 1024 for adjusting the gain of the VGA 1009 and generates a digital timing control

signal on lines 1022 for correcting timing applied to a voltage controlled oscillator (VCO) 1024. Digital signals on lines 1017 are supplied by the digital filter 1016 to a tracking gain and timing control 1026. Tracking gain and timing control 1026 generates a digital gain control signal on lines 1027A for adjusting the gain of the VGA 1009 and generates a digital timing control signal 1025 for correcting timing applied to a voltage controlled oscillator (VCO) 1024 during the tracking mode of operation. The disc drive 100 includes various electronics 160. Part of the electronics is a recording channel 1000.

Referring briefly to FIG. 3, a disc 134 is shown having zones 0, 1, 2 and N. Each zone 0, 1, 2 and N includes a plurality of tracks. Corresponding tracks on different disc surfaces can be said to resemble a cylinder. A cylinder is a group of tracks at substantially equal radial distance. A zone 0, 1, 2 and N can also be said to be formed of a number of cylinders when a plurality of recording surfaces are discussed.

The present invention operates with a disc drive such as the disc drive 100 shown in Fig.1. The present invention utilizes poorly performing heads within a cylinder rather than discarding or reworking them during the manufacturing and testing process. Tests are performed to identify head quality based on common quality standards for a particular drive and a particular manufacturer. According to one aspect of the present invention, lowering the recording frequency improves the data quality of the "frequency-adjusted heads", sometimes termed "less-than-nominal heads", and results in better error rates to improve yield (i.e., the proportion of disc drives considered "good"). In situations where frequency-adjusted heads are used with a lower recording frequency, the heads are sometimes called "optimized heads"; because those heads are operated at a recording frequency that has been optimized for recording characteristics of the particular heads. Accordingly, a nominal, non-frequency-adjusted, or non-optimized head is a disc head that meets the desired data quality specifications of the particular drive and particular manufacturer without changing the nominal recording frequency. Lowering of the recording frequency is termed "optimizing" the recording frequency, (optimizing of the heads involves enabling the recording frequency to be varied on a head-by-head basis within a zone structure). Furthermore, frequency-adjusting may reduce the necessity of manufacturing rework of heads in a disc drive. Additionally, a masking or translation process via software assists the processor to locate a target physical address on a disc drive having recording frequencies varied on a head basis within a cylinder.

In some embodiments, a frequency-adjusted head (i.e., one that is operated at a lower-

than nominal frequency in one or more of the zones) will record less data on its corresponding disc surface, as compared to the nominal amount of data for a surface. In some such embodiments, one or more of the other heads (i.e., the "nominal heads") will be operated at a higher frequency, thus recording more than the nominal amount of data, in order to compensate for the lower amount of data on the frequency-adjusted head's surface, and thus maintain the total amount of data for the disc drive as a whole at the desired level. For example, if each disc surface is designed to store one gigabyte of data in a disc drive having five platters and thus ten disc surfaces, the total disc drive would provide ten gigabytes of data storage. If one head were found to have characteristics that indicated it would operate at a given error rate only if using a recording frequency of, for example, about 99% of the nominal recording frequency in one or more zones (resulting in less than one gigabyte of data on that surface), the other nine nominal heads could be operated at about 100.2% of the nominal recording frequency in those same zones (resulting in more than one gigabyte of data on their surfaces). Thus, in such embodiments, an overall improved disc-drive error rate is achieved by slightly lowering the amount of data and lowering the recording frequency for certain (but not all) of the transducers and their corresponding disc surfaces, while slightly increasing the amount of data and the recording frequency for other of the transducers and their corresponding disc surfaces. At the same time, the total amount of data stored (or storable) on such disc drives can be maintained.

In one embodiment, the method is optimized to read large amounts of data sequentially. In another embodiment the method is optimized for a read/write function that has a serpentine-like structure, due to frequency-adjusted head subzones that are intermixed with non-frequency-adjusted head subzones. The present invention also reorganizes the current zone structure to accommodate the head frequency variation within a cylinder.

One embodiment divides the n original zones into at least n+1 subzones. Each subzone services a variable number of cylinders with a fixed number of heads. The fixed number of heads may vary from one subzone to another, but remains fixed within a subzone. As a result, the number of heads are maintained as a zone specific parameter. One example embodiment of the present invention is well-suited for operation in a headerless architecture environment. Such an environment exists where the data address header or tag no longer resides on the disc itself. Instead, the header is in the controller's memory or the volatile random access memory, "RAM", which is associated with the circuitry 160 shown in FIG. 1.

FIG. 4 is a pictorial depiction of a grid-like layout of a disc drive 100, wherein the

heads are logically addressed under a logical block address ("LBA") scheme. The diagram 200 of FIG. 2 shows several heads 210 accessing several tracks 220. For instance, cylinder 0 consists of all of the tracks below the heads 210 (in this example, Head 0, Head 1, Head 2, Head 3, Head 4) that are vertically aligned along the first tracks of the several discs, wherein each head corresponds to one disc surface. Each disc 134 has two recording surfaces. Head 0 is associated with a top surface of a first disc 134 in disc drive 100 and head 1 is associated with the bottom surface of the disc 134. Head 2 is associated with the top surface of a second disc and head 3 is associated with the bottom surface of the second disc. Head 4 would be associated with one surface of a third disc. Although the invention is described for a disc drive 100 having multiple discs, it is contemplated that it could also be applied to a disc drive 100 using a single disc 134.

Cylinder 1 is the next vertical alignment of tracks amongst the several discs, and likewise for cylinder 2 through cylinder n, the maximum number of cylinders available for general use. Solid line arrows 240, 242 and 244 show that during a read operation, the information beneath the various heads 210 is read for an entire cylinder. In other words, within cylinder 0, the information below head 0 is read first, then the information below head 1, then the information below heads 2, 3 and 4. The dotted line, such as dotted line 241, depicts an access to the next track and cylinder 1 and a head switch from head 4 to head 0. Solid line arrow 242 shows head switches after reading information beneath the heads in cylinder 1. Solid line arrow 244 shows reading all of the tracks containing data or information in cylinder 2. Dotted line 243 shows the switch between cylinder 1 and 2. One aspect of the invention is to determine if one or more of the heads 0, 1, 2, 3, or 4 performs more poorly than the rest of the heads. If a head or heads is a poor performer, it has been found that by reducing the frequency of the read channel for the poorly performing head or heads, the performance is very much improved. The improvement is indicated by a drop in the errors associated with the poorly performing head. The recorded channel or data channel frequency is reduced for the poorly performing heads within a zone. Thus, within a single zone the recording channel may operate at least two different frequencies, one frequency associated with the good heads and another frequency associated with the poorly performing head or heads. In order to keep the information capacity of a zone equal to the capacity of the zone before frequency-adjusting, the recording frequency associated with the good heads may be increased.

The LBA increases horizontally from left to right, and from cylinder 0 until the last

cylinder in the reserve zone 280. The reserve zone 280 is typically at the inner diameter of the disc 134. In the reserve zone 280, system data exclusively resides in a predetermined designated portion of the drive. Similarly, the heads 210 are numbered sequentially and vertically on the left side of the diagram, ranging from 0-4. The tracks are either accessible user tracks or spare tracks interspersed throughout the drive. Spare tracks are individual reserved tracks that are available for data placement when a normal user track contains a bad sector.

To access the data each head reads or writes along its corresponding tracks within an entire cylinder, unless the head encounters a spare track. Since only one head is enabled at any given instant, the head reads information at different times from the track beneath head 0, head 1, head 2, head 3 and head 4. Thus, for cylinder 0 heads 0-4 are unimpeded and are able to access the all the data within cylinder 0, beginning with head 0 and ending with head 4. Afterwards, the actuator moves to the first track 220 in cylinder 1, once again beginning with head 0 and ending with head 4; each head accesses the corresponding data on the track without any interruptions. However, in cylinder 2, heads 3 and 4 encounter spare tracks that interrupt the data transfer.

Cylinders zero, one, and two are grouped together to form original zone 0, also referred to as zone 230. Likewise, cylinders three, four, and five make up original zone 1, also referred to as zone 240. System data, that includes information regarding the quality of the transducer user heads and formatting of tracks, is placed within a reserve zone 280 made of several non-accessible cylinders that are contiguously grouped. In an original zone shown in FIG. 2, the frequency of the recording channel is the same for all the heads 210 within the original zone. In other words, all the heads 210 are determined to be good and none have to be frequency-adjusted. The zones have different recording densities in each zone. Similar cylinder groupings exist for the remaining usable cylinders. Finally, a number of non-usable cylinders that contain system data make up the reserve zone 280.

FIG. 3 is a block diagram 300 showing several original zones 310, 330, and 350 after a head or heads in the disc drive have been frequency-adjusted. The frequency-adjusting of a head or heads gives birth to a subzone for each zone. A subzone is produced for each different recording frequency at which the various heads operate at. For example, if one head is determined to be a poor performing head, each zone will include two subzones. Subzone 00 will have information recorded at a first frequency and subzone 01 will have information recorded at the frequency-adjusted head frequency. As shown in FIG. 3, the zone can be

divided into N subzones. The maximum number N of subzones will be equal to the maximum number of heads 210 in the disc drive 100. In other words, each head writing at a different frequency would have its own subzone. The original zones are numbered 0,1, ...,n. In an example embodiment, original zone 310 corresponds to original zone zero 230 of FIG 4. Likewise, original zone one 330 corresponds to original zone one 240 of FIG. 4, and so on through zone n 350 of FIG. 5 corresponding to zone n of FIG. 4. Each one of the original zones is divided into corresponding subzones, 320, 340, and 360. In an example embodiment, zone zero 310 has several subzones 320 labeled with a zone identifier of 0, followed by the subzones specific numerical ordering status, i.e., subzone 00, subzone 01, subzone 03, subzone 04,..., subzone 0n. Thus, subzone 00 corresponds to original zone zero, subzone 0. Likewise, subzone 01 corresponds to original zone 0, subzone 1, and so on.

Zone one 330 has a subzone structure 340, wherein the zone identifier is 1. Thus, zone one 330 is partitioned into the following subzones: subzone 10, subzone 11, subzone 12, subzone 13, ..., subzone 1n. Additional zones and subzones are within the scope of this invention and are depicted as zone N 350, partitioned into NN subzones 360. In another embodiment, several of the subzones may be combined into one, thus minimizing the total number of zones to maintain by the hardware and the software.

In another example embodiment, consider a drive that has a total of five heads reading information from discs 134 formatted with four original zones and twelve tracks from twelve cylinders. Of course, an actual disc drive 100 will have many more tracks and many more cylinders. The disc drive will also generally have an even number of heads. If two of the five heads are frequency-adjusted to a single lower frequency, then the four original zones are divided into two subzones. Each original zone is divided into two sub- zones, one set of sub-zones that service the first three logical heads on all cylinders, and another set of sub- zones that service the next two logical heads on all cylinders. In another example, if the frequency of the frequency-adjusted heads is lowered by 0.5% in every one of the original zones, then the original zones are divided into a total of eight subzones.

FIG. 6 is a graph of the frequency in bit density for various zones and subzones. The zone graph 400 has a horizontal axis 402 consisting of sequentially numbered original zones (Zone 0 - Zone N), and a vertical axis 404 representing increasing bit density with a unit of megabits per second (MB/s). Zone 0 is the outermost zone and zone n is the innermost zone containing user information. When the zones decrease in recording density, a step-like function 406 results. Normally, at the outer diameter of a disc, at zone zero, the highest

frequency or bit density is recorded. Similarly, the subzones of the corresponding original zones are graphed along a horizontal and vertical axis arrangement 472 and 474 respectively, and may have similar step-like responses 476 and 478. As indicated in FIG. 6, subzone 01 corresponds to a component of original zone zero (such as original zone zero 310, shown in FIG. 5) and to subzone 01 of FIG. 5 as depicted in the division of 320. However, one difference in the subzone graph 470 is that one or more of the subzones of the same original family 478 will have lower bit densities than other subzones in the same original family 476 since there is a lower recording rate for some heads in the zone. In the aforementioned example, one set of subzones has a higher head service load than the other set. Thus, it may be advantageous to sort the sub- zones in a descending (head service load) order as shown in FIG. 6.

With the ordering of the subzones based on head load, the sustained data transfer rates will gradually decrease as the zones themselves decrease in bit density, from higher density zones to lower density zones. The data transfer rate, however, will surge as the zones expand towards subzone 30 and enter subzone 01, then gradually decrease again. Subzone zero-one 477 will have lower bit density, because of the inclusion of a lower performing head, than subzone zero-zero 475 from the same original zone. An algorithm will be used to view and sort the subzones.

Because the head is still on the outer diameter, there could be a high bit density, but not as high as the density of a good head. And yet, the head in the new zone has a greater density than the good head of the inner diameter of the disc. The frequency for good performance from the heretofore lower performing head depends on manufacturing considerations.

Another embodiment of the present invention is a method of reusing lower performing read/write heads by varying the frequency of the read/write head within a cylinder. The method determines a physical location of a target logical block address ("LBA"). One type of arithmetic logic unit ("ALU") requires that the number of heads are known in order to translate a given LBA. Accordingly, a zone table is used for determining a target zone and the number of heads serviced by a zone. Firmware searches the zone table to determine the zone of the target LBA. Once the target zone is determined, the number of heads serviced by the zone can also be determined based on its position in the zone table (in both sorting methods: frequency sorting and head load sorting). An alternative could be to use the ALU resource itself, just to identify the zone and thus number of heads.

Using the number of heads determined above as an input, the ALU resource can be used again to calculate the physical sector, head and cylinder location of the target LBA. Note that the head number returned by ALU is the frequency-adjusted head number within the subzone. If the target LBA is in a frequency-adjusted head zone, the frequency-adjusted head number will have to be adjusted.

In FIG. 7 a pictorial depiction of the logical block addressing (LBA) scheme 500 for sequential read/write accessing is displayed. The grid-like layout is structured similarly like FIG. 4. That is, the user tracks within a single cylinder are accessed by the heads until a spare track is encountered or the tracks are no longer available for accessing. In one example embodiment, several user tracks are accessed according to the three non-frequency-adjusted heads 510 (Heads 0,1, & 2) within a single cylinder. Following this, the non-frequency-adjusted heads 510 sequentially access other tracks within another cylinder until eventually an entire group of cylinders, known as a zone, has been accessed. Within this example, all of the non-frequency-adjusted subzones 530 are accessed initially starting at cylinder 0 and proceeding to cylinder N. Later, all of the frequency-adjusted subzones 520 are accessed by the frequency-adjusted heads 512 (heads 3 and 4). The reading of all the frequency-adjusted heads starting at cylinder 0 and proceeding to cylinder n. In one embodiment, the addressing scheme has a reserved zone. The reserved zone has system data exclusively within its cylinders and thus does not store user data. In one embodiment, frequency-adjusting of heads does not occur in the reserved zone. All heads in the reserved cylinders should share the same frequency to avoid firmware complexities in dealing with frequency-adjusted heads in the reserved zone.

Thus, according to the example embodiment shown in FIG. 7, the original zones are divided into subzones. In this embodiment, the LBA scheme is optimized to read large amounts of data sequentially and with fewer interruptions. When reading the discs 134 in the embodiment shown in FIG. 5, all the non-frequency-adjusted heads read all the information under the non-frequency-adjusted heads. Thus, the actuator moves from the outer diameter to the inner diameter from one adjacent cylinder to the next. Access time is minimized. Time devoted to switching frequency in the recording channel is also minimized. Next, the actuator is moved back to cylinder 0 and data is read from all the frequency-adjusted heads in a similar fashion. Again, accesses are minimized since movement is from cylinder to adjacent cylinder. Frequency switching is also minimized. Resolution performance is greater with this particular LBA scheme.

FIG. 8 displays an LBA scheme wherein all the subzones of an original zone are accessed before accessing the subzones of another original zone. First the non-frequency-adjusted heads of the zone, and then the frequency-adjusted heads of the same zone (a separate subzone of the original zone) are accessed. All the subzones of an original zone are read before moving to another zone. This is known as serpentine-by-head formatting and is based on the frequency-adjusted heads. A reserved zone for system data also exists in FIG. 8 similar to the reserve zone in FIG. 7. In the example embodiment shown in FIG. 8, the LBA scheme is organized in a serpentine like manner because the frequency-adjusted head subzones are intermixed with non-frequency-adjusted head subzones. Such an LBA scheme is well suited for accessing small data segments and requires more accessing time than the sequential LBA scheme of FIG. 7. However, resolution performance may suffer (i.e., a time increase for getting uninterrupted information) from the frequent access interruptions, sometimes referred to as "seek times." The increased access time is explained repeatedly accessing a higher density zone immediately prior to a lower density zone.

It should be further noted that where an embodiment has data segments in a headerless-type format, the format map is generally located in RAM to inform the drive where on each track each sector exists, and ultimately which sectors have been marked lower performing.

FIG. 9 is a flowchart 700 of an example embodiment that provides a method for improving an error rate of a disc drive with read/write heads. The method includes determining the storage surface of a disc assembly (block 715); transducing data at a first frequency (block 720); transducing data at a second frequency (block 730); dividing a zone into subzones (block 740); and organizing subzones (block 750).

FIG. 10 is a schematic view of a computer system. Advantageously, the invention is well-suited for use in a computer system 2000. The computer system 2000 may also be called an electronic system or an information handling system and includes a central processing unit, a memory and a system bus. The information handling system includes a central processing unit 2004, a random access memory 2032, and a system bus 2030 for communicatively coupling the central processing unit 2004 and the random access memory 2032. The information handling system 2002 includes a disc drive device which includes the ramp described above. The information handling system 2002 may also include an input/output bus 2010 and several devices peripheral devices, such as 2012, 2014, 2016, 2018, 2020, and 2022 may be attached to the input output bus 2010. Peripheral devices may

include hard disc drives, magneto optical drives, floppy disc drives, monitors, keyboards and other such peripherals. The computer system 2000 operates as a stand-alone computer system or operates in a networked environment using logical connections to one or more remote computers. Any type of disc drive may use the method for loading or unloading the slider onto the disc surface as described above.

Advantageously, the method described for varying recording frequency on a head basis within a cylinder of a disc drive works particularly well in a headerless architecture environment. The performance of the lower performing heads can be improved. Moreover, better error rates are achieved, thus overcoming yield problems. The invention may result in increase accuracy of arithmetic logic unit (ALU) calculations without having to change the engine that performs the calculations. In addition, it is likely that the discarding or reworking of entire drives, as a result of lower performing heads, becomes less.

Conclusion

One aspect of the present invention provides a method for improving reading and writing information to a disc drive with read/write transducers. The method includes the steps transducing data at a first frequency when in a first zone of a first storage surface of a disc assembly, transducing data at a second frequency that is different than the first frequency when accessing the first original zone of a second storage surface of the disc assembly. A dividing step expands the first original zone structure into subzones, and furthermore maintains a parameter for each subzone that represents the number of heads associated with the subzone.

In some embodiments of the method just described, the number of heads are maintained as a zone specific parameter. In other embodiments, several subzones are combined into one. Still in other embodiments, one subzone originating from a zone is of a different bit density value than another subzone originating from the same zone.

In other example embodiments of the described method, dividing of subzones further includes steps that compare a number of sectors in a nominal transducer domain with a total number of sectors in a frequency-adjusted transducer domain, and using the nominal transducer domain where a total number of sectors in the nominal transducer domain is significantly higher than the total number of sectors in the frequency-adjusted transducer domain. Further example embodiments of the described method comprise organizing subzones, including using a recorded frequency of the subzone, comparing recording

densities of one nominal subzone with a successive nominal subzone, and analyzing whether cylinder switches are offset.

Still another aspect of the present invention provides an improved disc drive. This disc drive includes a rotating disc assembly having a first disc surface and a second disc surface. The disc drive also includes a first head operating in a transducing relationship to the first disc surface and at a first frequency in a first disc original zone, and a second head operating in a transducing relationship to the second disc surface but at a different frequency than the first frequency when operating in the first original disc zone. Moreover, the aforementioned first zone comprises an equivalent radius range of corresponding tracks on each of the storage surfaces.

In some embodiments of the disc drive, the first zone is partitioned into a plurality of subzones and a first subzone is associated with the first head, and a second subzone is associated with the second head.

In some embodiments of the disc drive, at least some one of the frequency of one subzone is selected so that the associated first head and second head has increased performance.

Another embodiment of the present invention provides a sorting method, wherein the first and second subzones are sorted based on head load. A separate embodiment provides an alternative sorting method, wherein the first and second subzones are sorted based on frequency.

Another aspect of the present invention provides a magnetic disc storage system that includes a magnetic disc with a recording surface proximately positioned to a read/write transducer. The read/write transducer reads and writes information on the recording surface. At the same time, a memory is coupled within the disc storage system and similarly coupled to the read/write transducer. The memory contains an offset value of a servo position and a controller coupled within the disc storage system. The controller, the memory, and the read/write transducer are coupled. Moreover, the controller positions the read/write transducer in the disc storage system over a target address as a result of an input based on number of frequency-adjusted heads, wherein a frequency-adjusted head is a head operated at a lower frequency. Some embodiments of the just described magnetic disc storage system further include a data segment that has a headerless format.

Other example embodiments of the described system include an original zone comprised of an equivalent radius range of corresponding tracks on each of the storage

surfaces, and a predetermined plurality of such zones. Accordingly, a subzone is a partition of an original zone comprising an equivalent radius range of corresponding tracks on each of the storage surfaces. In another example embodiment of the described system, an information-handling system is operatively coupled to transmit data to and from the magnetic disc, along with an input/output subsystem that is operatively coupled to input and output data to the information-handling system, and finally including a memory that is coupled to the information-handling system.

Yet, another aspect of the present invention provides a system for reusing a lower performing read/write head. The system for reusing a lower performing read/write head includes a plurality of recording zones for storing data while varying the frequency among recording zones. Hence, the error rate, caused by lower performing read/write heads, is dramatically improved. In addition, there are a plurality of read/write heads for reading and writing data on a storage medium, a plurality of cylinders that are accommodating the read/write head frequency variation, and a zone table for determining a target zone and the number of heads serviced by a zone. In other embodiments, an ALU resource is used to identify the zone and number of heads associated with the above described system. Still in another embodiment, the ALU resource calculates a physical sector, head, and cylinder location of a target LBA, thereby resulting in a frequency-adjusted head number within a subzone.

Still another aspect of the present invention is a disc drive that includes a disc having a first surface further comprised of a first zone and a second zone. Likewise, the disc drive has a second surface further comprised of a first zone and a second zone, wherein tracks of the first zone of the second surface correspond to tracks of the first zone of the first surface. In addition, the disc drive has a means for minimizing error rate within one of the first zones.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A method for improving reading and writing information to a disc drive, the disc drive having read/write transducers, the disc drive including a disc assembly having at least a first storage surface and a second storage surface, the first storage surface and the second storage surface being formatted into at least a first original zone and a second original zone, wherein the first original zone includes an equivalent range of corresponding tracks on each of the storage surfaces, the method comprising steps of:

(a) transducing information at a first frequency when in the first original zone of the first storage surface;

(b) transducing information at a second frequency that is different than the first frequency when in the first original zone of the second storage surface of the disc assembly.

2. The method of claim 1, further comprising a step of:

(c) dividing the first original zone into at least two subzones.

3. The method of claim 2, wherein for each read/write transducer the dividing step (c) further includes maintaining a parameter for each subzone that represents the number of transducers associated with the subzone.

4. The method of claim 3, wherein the dividing step (c) further comprises organizing one subzone originating from a zone according to bit density value different than another subzone originating from the same zone.

5. The method of claim 1, wherein dividing step (c) further includes steps of:

(c)(i) comparing a number of sectors in a nominal transducer domain with a total number of sectors in a frequency-adjusted transducer domain; and

(c)(ii) using the nominal transducer domain where a total number of sectors in the nominal transducer domain is significantly higher than the total number of sectors in the frequency-adjusted transducer domain.

6. The method of claim 1, further comprising a step of

(d) organizing subzones, which further includes steps of:

(d)(i) using a recording frequency of the subzone;

(d)(ii) comparing recording densities of one nominal subzone with a successive nominal subzone; and

(d)(iii) analyzing whether cylinder switches are offset.

7. A disc drive comprising:

a rotating disc assembly having a first disc surface and a second disc surface;

a first transducer operating in a transducing relationship to the first disc surface and at a first frequency in a first disc original zone; and

a second transducer operating in a transducing relationship to the second disc surface but at a different frequency than the first frequency when operating in the first original disc zone, wherein the first zone comprises an equivalent radius range of corresponding tracks on each of the storage surfaces.

8. The disc drive of claim 7, wherein the first zone is partitioned into a plurality of subzones, a first subzone associated with the first transducer and a second subzone associated with the second transducer.

9. The disc drive of claim 8, wherein at least one of the frequency of one subzone is selected so that one of the associated first transducer and second transducer has increased data quality performance relative to the other of the associated first transducer and second transducers.

10. The disc drive of claim 8, wherein the first and second subzones are sorted based on transducer load.

11. The disc drive of claim 8, wherein the first and second subzones are sorted based on frequency.

12. A magnetic disc storage system, comprising:

a magnetic disc assembly having at least a first and a second recording surface;

a read/write transducer positioned proximate to the first recording surface of the magnetic disc for reading and writing information on the first recording surface;

a memory coupled within the disc storage system and coupled to the read/write transducer, where the memory contains an offset value of a servo position; and

a controller coupled within the disc storage system and coupled to the read/write transducer and the memory, where the controller positions the read/write transducer in the disc storage system over a target address as a result of an input based on a total number of optimized transducers, wherein an optimized transducer is a transducer operated at a lower frequency.

13. The magnetic disc storage system of claim 12, wherein a data segment that is recorded on the first recording surface has a headerless format.

14. The magnetic disc storage system of claim 12, wherein an original zone formatted on both the first and the second recording surfaces comprises an equivalent radius range of corresponding tracks on each of the storage surfaces, and a plurality of such zones are predetermined.

15. The magnetic disc storage system of claim 14, wherein a sub-zone is a partition of the original zone comprising an equivalent radius range of corresponding tracks on each of the storage surfaces.

16. The magnetic disc storage system of claim 12, further comprising:

an information-handling system operatively coupled to transmit data to and from the magnetic disc;

an input/output subsystem operatively coupled to input and output data to the information-handling system; and

a memory coupled to the information-handling system.

17. A system for reusing a lower performing read/write transducer, comprising:

a plurality of recording zones for storing data, having a variance in frequency among the plurality of recording zones in order to improve the error rate caused by lower performing read/write transducers;

a plurality of read/write transducers for reading and writing data on a storage medium;

a plurality of cylinders which accommodates the read/write transducer frequency

variation; and

a zone table for determining a target zone and the number of transducers serviced by a zone.

18. The system of claim 17 wherein an arithmetic logic unit (ALU) resource is used to identify the zone and number of transducers.

19. The system of claim 18 wherein the ALU resource calculates a physical sector, transducer and cylinder location of a target logic block address (LBA), resulting in a frequency-adjusted transducer number within a subzone.

20. A disc drive comprising:

a disc having a first surface further comprising a first zone and a second zone;

a second surface further comprising a first zone and a second zone, wherein tracks of the first zone of the second surface correspond to tracks of the first zone of the first surface; and

means for minimizing error rate within one of the first zones.

21. A disc drive comprising:

a first and a second read/write transducers; and

a disc assembly having at least a first storage surface in transducing relation with the first read/write transducers and a second storage surface in transducing relation with the second read/write transducers, the first storage surface and the second storage surface being formatted into at least a first zone and a second zone, wherein the first zone includes an equivalent range of corresponding tracks on each of the storage surfaces, wherein a first amount of data is recorded in the first zone of the first storage surface, and a second amount of data, different than that first amount of data is recorded in the first zone of the second storage surface.

22. The disc drive of claim 21, wherein the first zone is partitioned into a plurality of subzones, a first subzone associated with the first transducer and a second subzone associated with the second transducer.

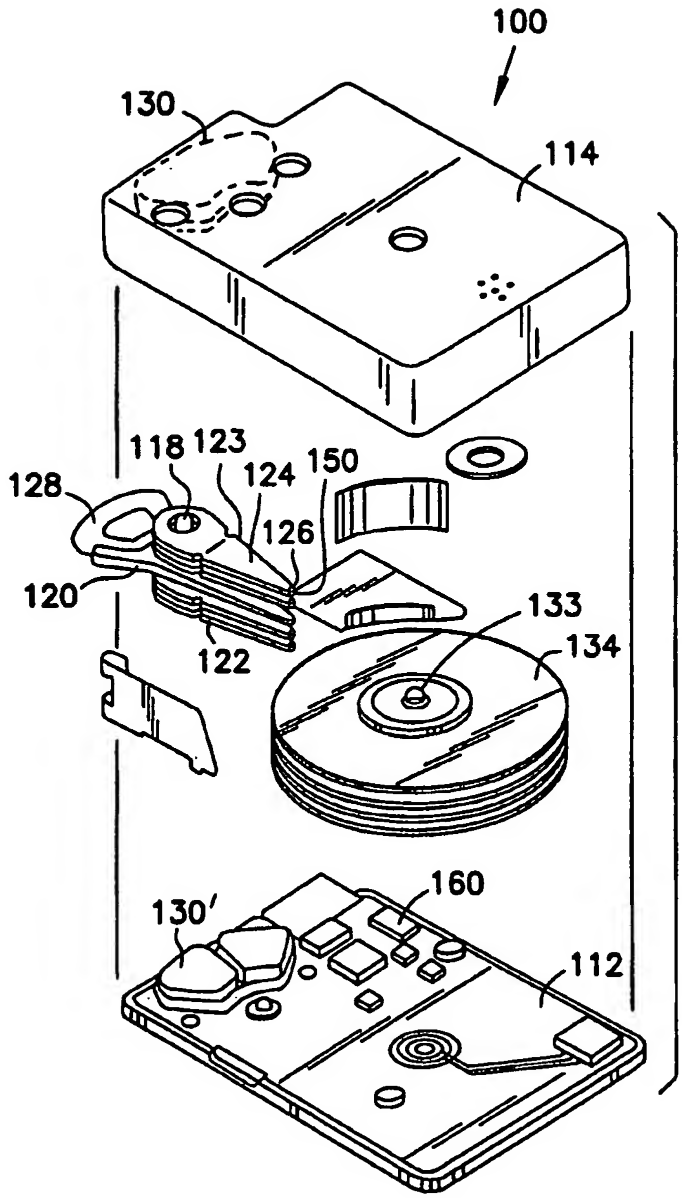
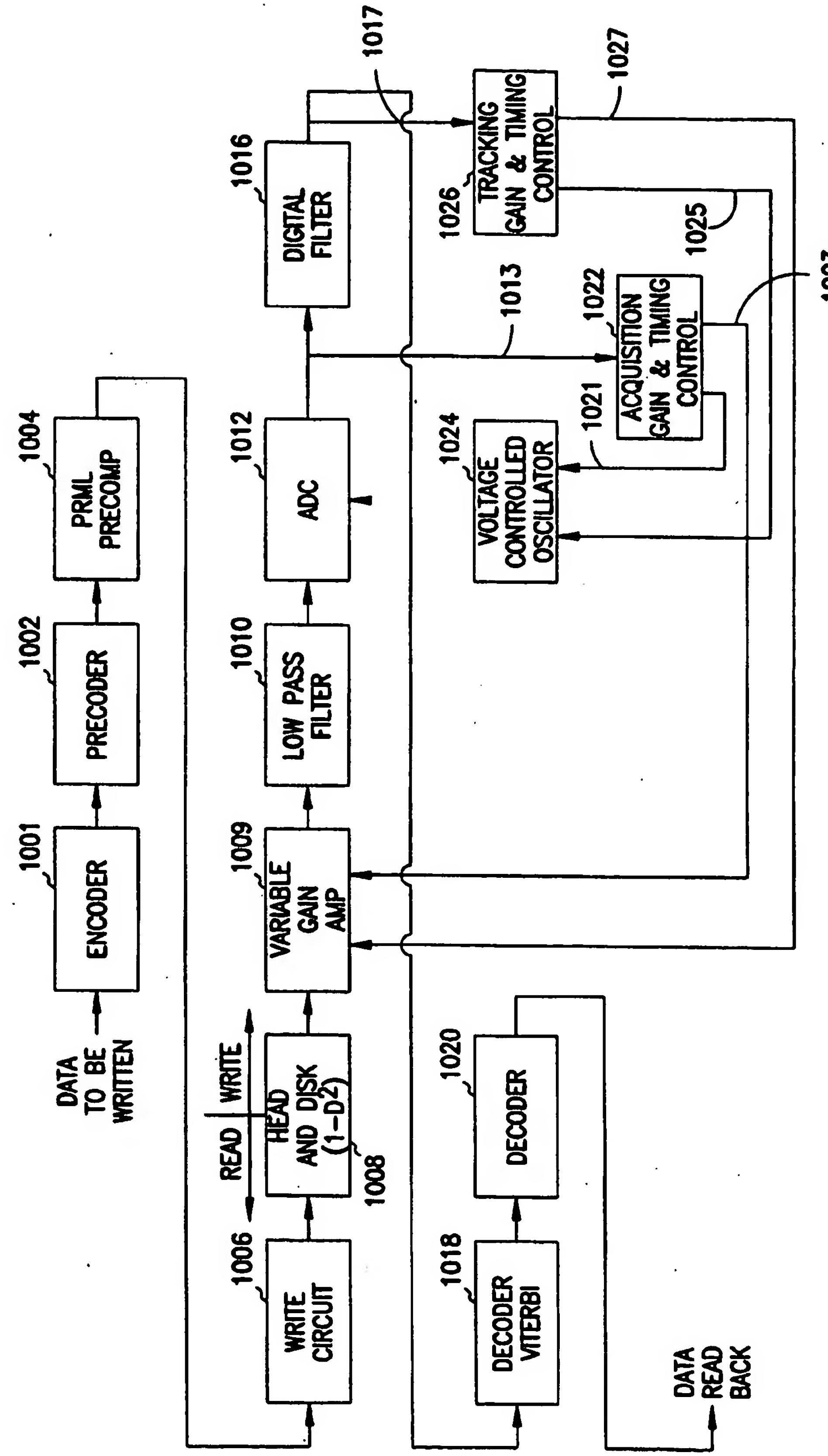


FIG. 1



DATA TO BE WRITTEN
ENCODER
1001
PRECODER
1002
PRML PRECOMP
1004
WRITE CIRCUIT
1006
READ
WRITE
HEAD AND DISK (1-D2)
1008
VARIABLE GAIN AMP
1009
LOW PASS FILTER
1010
ADC
1012
1013
DIGITAL FILTER
1016
1017
DECODER VITERBI
1018
DECODER
1020
DATA READ BACK
VOLTAGE CONTROLLED OSCILLATOR
1024
1021
ACQUISITION GAIN & TIMING CONTROL
1022
1023
TRACKING GAIN & TIMING CONTROL
1026
1025
1027

FIG. 2

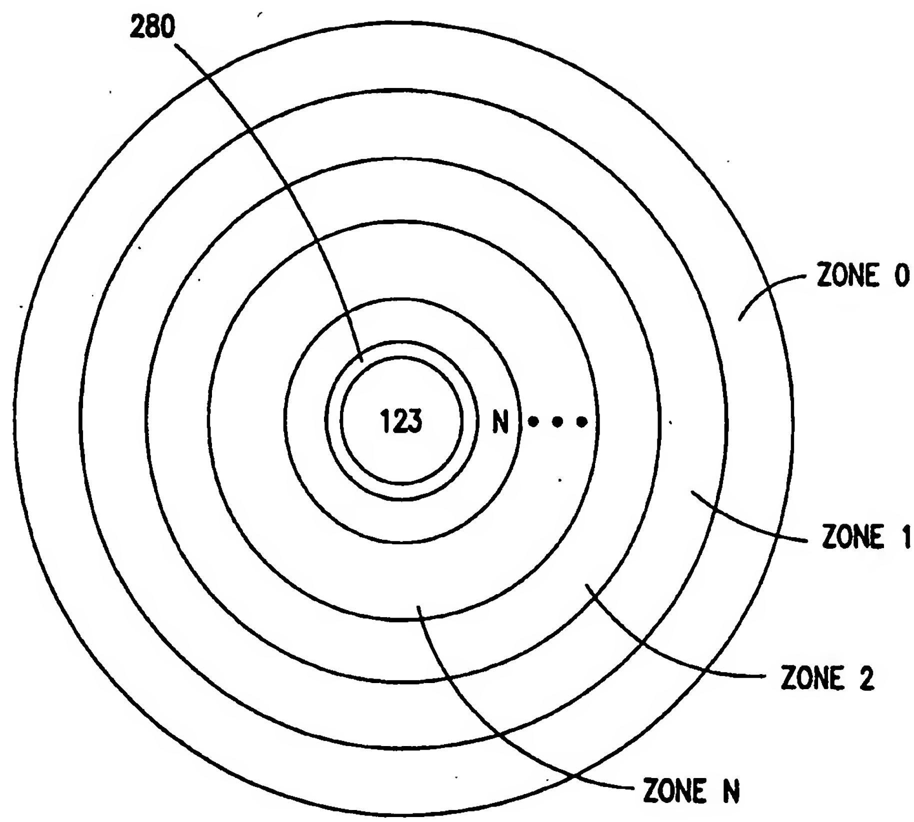


FIG. 3